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D09120031

DT009-3 Electrical energy and control systems



Final year project

The Wind farm effect to the Distribution system

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1. Introduction

Main goal in this thesis that it gives view how wind production effect to distribution system. For this I have used material from Fortum and Tampere University of Technology. There is also section which tell main point of Finnish power system and wind production in Finland. Example target I selected Högsårans wind farm which contains new technology of wind energy production. Second main point is learn how distribution network operate and what things has to look for to planning distribution system. Thesis is extensive and that reason it could not concentrate too deeply in one thing but I tried to focus in key points in every subject. I started to do this thesis without much knowledge of wind energy and thesis was also great learning process.

Forewords

I want to thanks very much Fortum and Tampere University of Technology both help me very much for making this thesis any information which I have get from both has been very useful and necessary for this thesis.

Terminology

PMG= Permanent magnet Generator

V= Voltage (U)

MW= Mega watt, term of power

Var= term of reactive power

I= Current (A)

Ω , Ohm= Impedance, resistance

DC= Direct current

AC= Alternating current

2. The Finnish power system

The Finnish power system has been open for free competition since 1995 and this has changed it very much. This means for customers that they could change their electricity company when ever they want. Finland has around 100 companies which sell electricity or product to customers, most of these companies are cities owned local companies. Before market opening companies was more but now big operators are selling smallest, two biggest are now Vattenfall and Fortum.

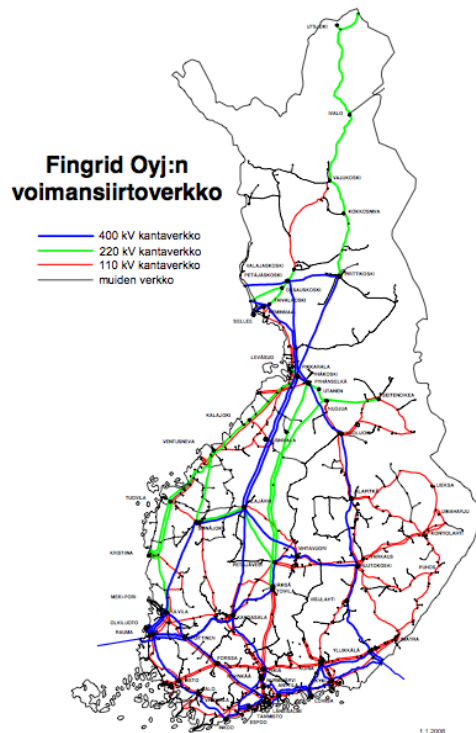
Electricity selling goes simple way, producers sell electricity to the Nordic countries electricity market pool (nord pool). This system is used in Denmark, Sweden, Norway and Finland. Every electricity seller has to buy electricity from nord pool at a certain price and sell on. Demand and production determine price.

2.1 Distribution system

The distribution system is owned by local distribution companies which are mostly combined with electricity selling companies. Local companies are responsible for these networks, most of the times the distribution lines voltage level is 20kV or 400V with only a few 110kV lines. Companies maintain these networks with their own personnel or use subcontractors. Financing they get from the distribution fee which is commonly 3.5-5 cent/kWh.

Fingrid has its own base grid which include most of 110kV, 220kV and 400kV lines. It has also secure electricity transmission in factories to consumers which is neutral and equal for each grid user, regardless of their status.

Picture 1 shows the base grid owned by Fingrid. The 400 kV line is like a spine to the whole distribution system. It goes to every place where there are significant consumers or production. The main import places can also be seen. South Finland is an important part of the distribution system because most people and industry are situated there.



Picture 1: Finnish base grid

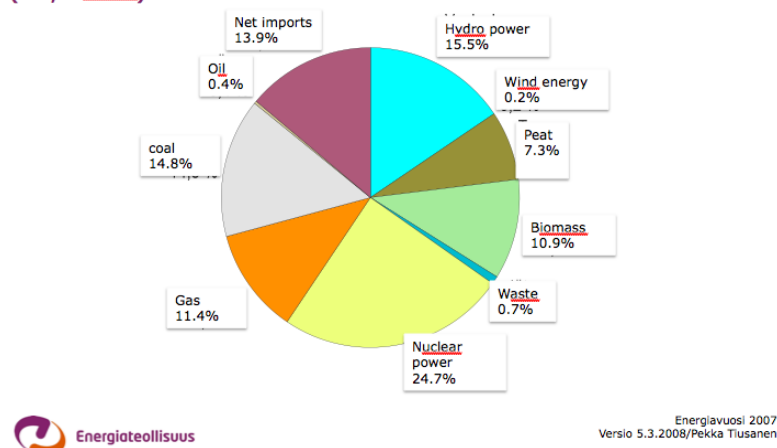
2.2 Electricity production

Finland has around 400 electricity plants, and energy demand is quite big because of the cold and long dark times during the winter. Electricity demand in winter was around 12GW in winter 2009/2010 depending of the weather.

The most used energy production source is Nuclear power in Finland and it was a base load. Finland has 4 nuclear plants and the 5th will be ready maybe in 2011. Finland's energy production is 61% carbon dioxide-free and 32% is renewable. Picture 2 shows the electricity

supply by fuel. In that picture can also be seen how dependent Finland is on imported electricity. Most of the electricity is imported from Russia via a DC link. Finland also has sea cables from Sweden and Estonia.

Electricity Supply by Fuel 2007 (90,3 TWh)



Picture 2: Electric supply by fuel

2.3 wind energy

only 0.2 or 0.3% of Finland's energy demands are produced by wind energy. At the end of 2009 there were 117 wind turbines in Finland with a total capacity of 146MW



Picture 3: Finland's wind farm location

Almost every wind farm is situated on the coast of the Baltic sea or in the tundra because those are only places where the average wind speed is more than 5 m/s. This is a general problem for the production of wind energy in Finland. However, Finland has published a total of 8000MW wind farm projects, these projects planned over 5800MW build to the offshore.

Wind farm connecting to grid takes normally 1 month to 18 months depending of location and are there need to connect to 110kV. Price of produced energy is dependent of market price and Finnish parliament processing statute for fixed payment of produced wind energy. First 3 years to 2015 price could be 105€/MWh and after that 80€/MWh but nothing are not closed definitely. Distribution charge of produced energy are maximum 0.7€/MWh

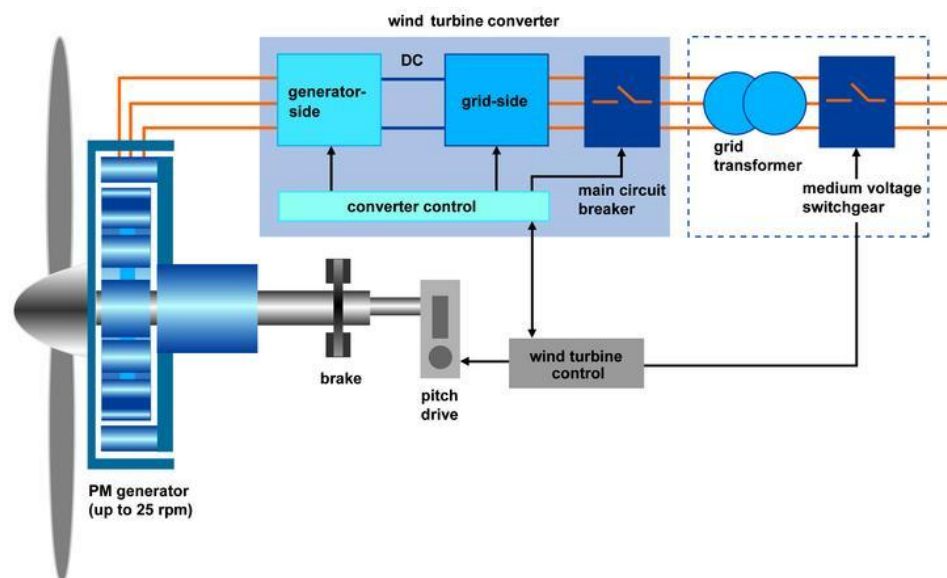
Picture 3 shows where the turbines are located. Finnish wind turbine locations are mostly on the coast.

3. Högsåran wind farm

Wind farm building and maintenance are very diverse because in Finland there are many different operators at every level. This is the reason why I focus only on one wind farm which is located in Högsåran near Hanko.

3.1 Plant

Högsårans wind farm was built by Hafmex and the components were supplied by ABB. The wind farm includes 3 plants and each one has a capacity of 2MW. The wind plants are ABB Z72 type. The farm is connected to a 20kV grid.



Picture4: Diagram of wind turbine apparatus and functionality

3.2 Generator

The plant generators are permanent magnets and they are also direct drive, so they would not need transmission. This makes the tower operational room smaller and the plants are more efficient and easier to maintain.

The PMG differs from the Induction Generator in that the magnetisation is provided by a Permanent Magnet Pole System on

the rotor, instead of taking excitation current from the armature winding terminals, as it is the case with the Induction Generator. This means that the mode of operation is synchronous, as opposed to asynchronous. That is to say, in the PMG, the output frequency bears a fixed relationship to the shaft speed, whereas in the mains connected induction generator, the frequency is closely related to the network frequency, being related by the slip. These differences will be discussed at length. (RIS-S)

PMG have the benefits of their robust construction and high efficiency, but the adverse side is the expensive price. Direct drive generators are basically the specialty synchronous machines. These are a sufficient number of poles so that the machine rotor can rotate at the same speed as the wind turbine. In this application, PMG and the turbine rotor form a single piece. The Generator is also very big and heavy, the ABB generator diameter is 4.2m and it weighs around 50 tons.

The generator can use slow or fast speed solutions. The advantage of slow speed solution is less noise. The disadvantage is when wind speed is unsteady this could cause instability to the electric supply. The Main disadvantage of PMG is that it does not readily provide a constant voltage, when the shaft speed and the load current vary.

3.3 Electric supply

When the generator is direct drive the plant needs a rectifier and transformer. The electricity is fed into the network, AC-DC-AC inverter and the operating principle of a special filter is fitted with a power adapter. This makes it possible to supply capacitive or inductive power to the grid. This allows the power quality to improve with plants. This also demands very much inverters and other power electronics.

3.4 Protection

Electrical protection is very important to equipments and distribution system specially when plant are powerful compare to the local distribution system. Protection are mostly concentrated to voltage and frequency protection. Wind turbines protection is also possible use remotely. Frequency transformer has multiple protections, voltage, current, power, ground contact and generator frequency. The following description describes the plant's protection to electrical network to the plant

First element from the grid is load isolator and circuit breaker which is remote controlled and there is also setups frequency and voltage which local distribution operator Fortum has demanded. Apparatus is ABB Uniswitch middle voltage apparatus. Uniswitch system are air insulated and rated current is 630A to 1250A and rated voltage is 12-24kV. short circuit capacity is 65/50kA and for 1 second time period it's 25/20kA

Every wind turbine has also own load isolator and circuit breaker there are also same Uniswitch apparatus. These apparatus don't have remote control gear.

Wind plant have also transformer 0.66kV/20kV and it's inside of the frequency transformer. It have circuit breaker which have overvoltage, overcurrent and earth contact protection. Circuit breaker are ABB SACE type air insulated circuit breaker. From frequency transformer to generator have also relay to additional protection because of permanent magnet generator. Air circuit breaker and generator protection relay has to operate to same time

3.5 Power control

Power control is an important part of the operation of wind plants, it helps control efficiency, output power, quality and avoid flickering. Most of the time this kind of solution is made with stall, active stall control or Blade pitch angle control.

3.5.1 Stall control

Stall control is simply used to rotate the plant slower than usual. The problem is that the power plant structure will have a greater strain in such situations, it is noisier and it is not so accurate, even though it is easy to accomplish and it's not needed for turning the blades.

3.5.2 Blade pitch angle control

Blade pitch angle control is more complicated to implement, because it needs motors to control the blade angle and also to control the circuit. The benefits are very great, it is not so stressing for the structure and every blade can be controlled separately and has a good starting torque.

Permanent magnet generators are not so dependent on this kind of controlling than fixed speed generators, because the speed change does not affect power quality directly.

3.5.3 Active stall control

Less than a rated speed of the wind I was able to stall the active (active stall control) the institution is operating as well as the shoulder angle I could see the wind power plant. Optimizing blade angle, which means a fixed-angle rotor blade compared to somewhat higher efficiency. When the wind speed exceeds the nominal wind speed, the blade starts to

stall as the passive stall restriction, but the stall time limit is governed by changing the blade setting angle, so that large wind power plant operates at speeds close to the rated power all the time. Shoulder angular body, like the active plant stall does not occur over power problems of low temperatures. When the wind speed increases more than the maximum wind speed, the body stop itself turning blades in the wind direction, wind trailing plain (incidence angle 180°)

4. Effects to grid

the grid demands changes when adding to decentralized production in the area. In that area there is only one supply from a 110/20kV substation. The area is also a typical Finnish rural area that is sparsely populated which is in addition to long transmission distances. The network analysis materials are from Tampere University of Technology and the grid data from Fortum.

4.1 changes to grid

Some parts of the network needed an increase in conductor cross-section surfaces of the increased load due to the grid. The Käsnäs output cable changed Pas-70 to Pas-150 and the cable to Sjöholmen doubled because of increasing current (87.5A to 175A when a I_{\max} is 135A) and the new cable to högsåran's island. Bergholmen needed also a Voltage increase transformer (20.36kV to 20.54kV).

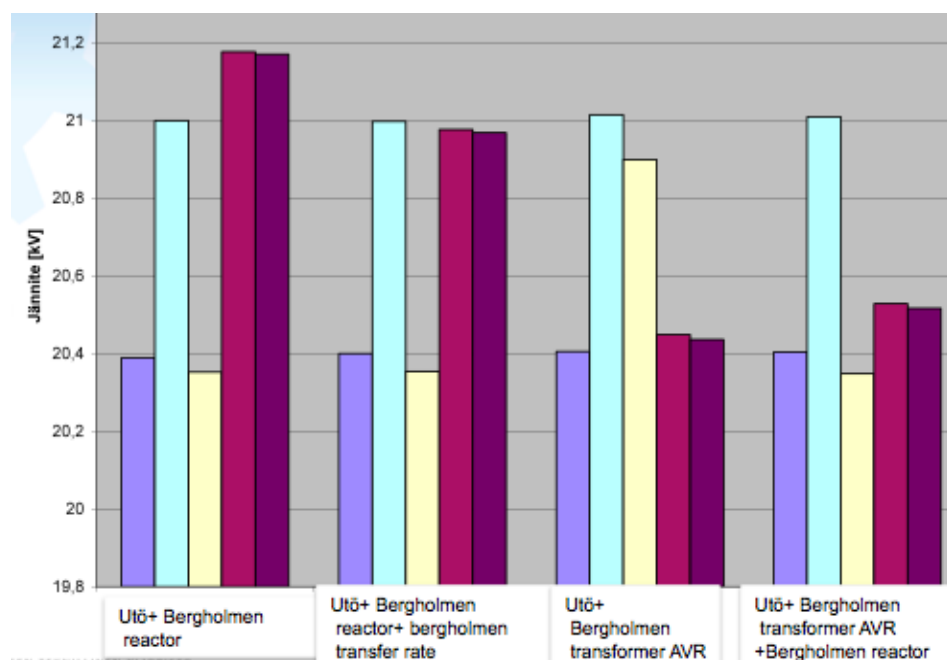
Production units are not allowed to supply power to the Byholmen output because it is not rated to such loads. In the case of disturbances the voltage could come back to the connection point via the Byholmen output because in this kind of situation the plant should not reconnect to the grid automatically until supply direction has been assured.

From the wind plant connection point it is possible to supply to the Byholmen output 800kW and -340kVAr of power.

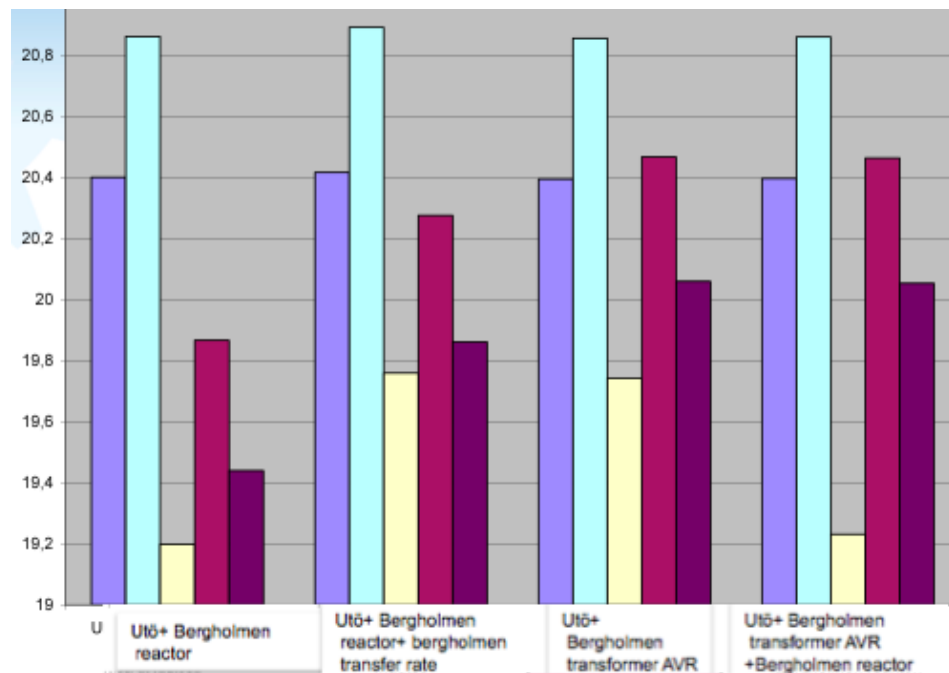
4.2 Voltage level changes to different loads

The grid minimum load was 12.8.2007 3am and the maximum load was 12.2.2007 12pm. Both load situations are measured from the Käsnäs output which is the output where the wind plants are located. The Byholmen output minimum and maximum load conditions are very different than the Käsnäs output.

The graphs below show how the voltage change in different places has different loading conditions. Blue= 20kV substation; light blue= reactor connection point; yellow= Bergholmen output; Red= Bergholmen secondary and Violet= Utö output.

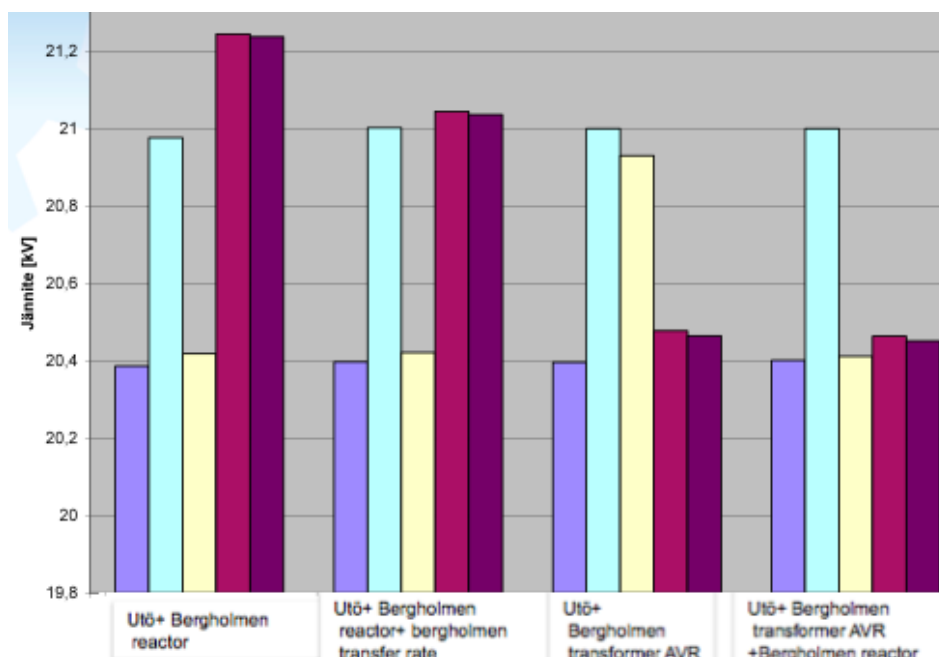


Graph 1 Shows the voltage level when the Käsnäs output is at minimum load condition

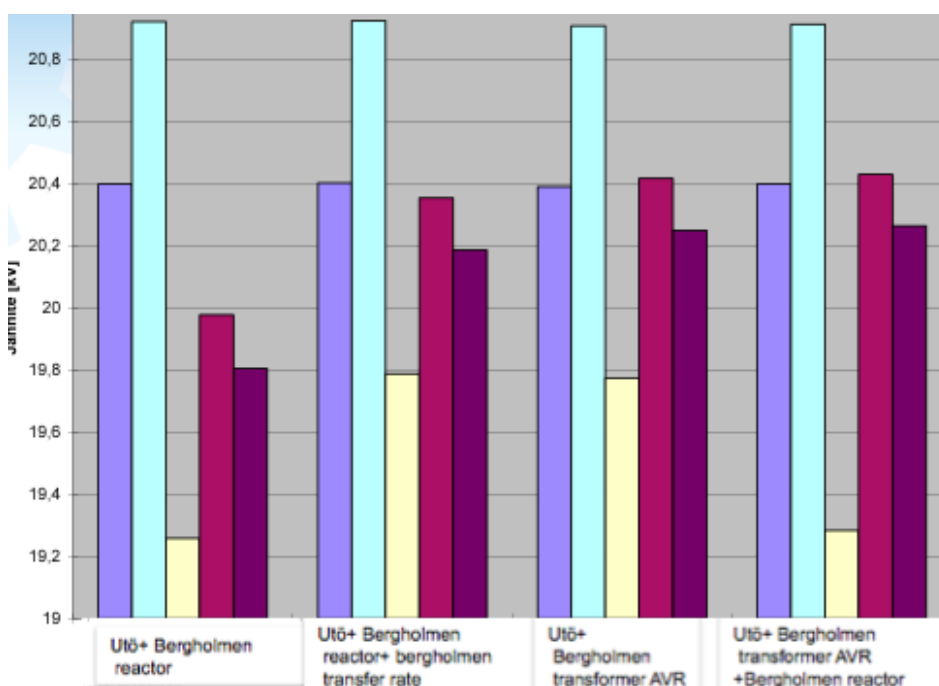


Graph 2 Shows the voltages level when the Käsnäs output is at maximum load condition

Graphs 1 and 2 show how the area voltage level varies when Käsnäs output is at minimum and maximum load condition. The 20kV substation voltage level is very stable in both situations. The reactors voltage levels are also very stable at every point and decrease only by 0.2 kV. The Bergholmen output situation is a little bit worse because the voltage level decreases 20.4 or 20.9kV to 19.2 or 19.8kV. The Bergholmen voltage increase transformer secondary voltage level stays almost the same excluding the two first measure points. The Utö output voltage level changes are almost the same as the Bergholmen secondary side.



Graph 3 shows the voltage level when Byholmen output is at minimum load condition



Graph 4 shows the voltage level when Byholmen output is at maximum load condition

Graph 3 and 4 shows the voltage level at the same point when the Byholmen output is at minimum and maximum load situations. Voltage levels remain much more stable as seen in this second output. The 20kV substation and plants connection points are very stable with only a

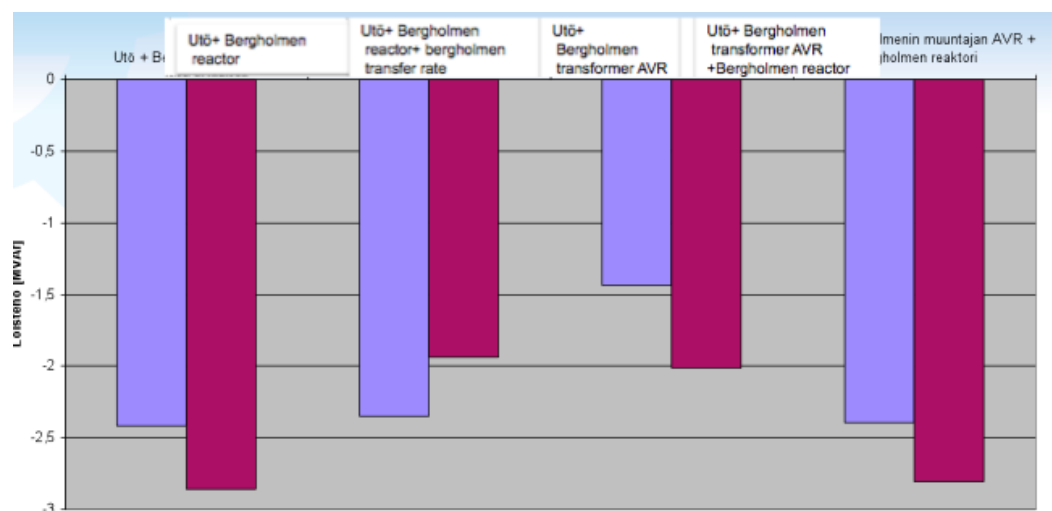
0.1kV change and at substation level there are no changes. But the same problem is Bergholmen output than first situation, the voltage level has dropped greatly. Bergholmen voltage increase transformer secondary voltage level drop only at Bergholmen reactor point and are stable other to point. The voltage level at Utö output behaves the same.

4.3 Losses in grid

Wind plants are synchronous reactors and for that reason they could affect losses at the local grid very well.

Only in Byholmen output do the active power losses decrease 130-166kW.

At maximum load condition the voltage could also go so low that the voltage increase transformer adjustment range could end. This situation plants has to control down of before greater harm. The wind farm reactive power consumption also increase the active power losses



Graph 5

Graph 5 shows the reactive power transmission to the local grid. Blue is the minimum load condition and red is the maximum load condition. Reactive loads are between 1.5 and 3 MVar.

The plant can also potentially save the cost of a compensation capacitor, because the plant uses reactive power from the grid.

4.4 Minimum and maximum voltage level and protection.

Plants should use power factor 1 for as long as possible, at minimum and maximum voltage level. The maximum level is 21kV to sizing of grid and the minimum level could be 20.4kV to maintain voltage level.

When reactive power capacity ends and voltage levels are higher than maximum voltage has to limit the plants active power production. This could be done with plant power control. In the plants they must have voltage level relays which protect plants and customers from down voltage and over voltage.

If over voltage reaches 110% voltage (22kV) the disconnection time will be 50ms which is a quick launch. If the voltage level is 106% (21,2kV) launch time is 60s. There is a specification for quick down voltage launch but when voltage level is 90% (18kv) the launch time is 10s.

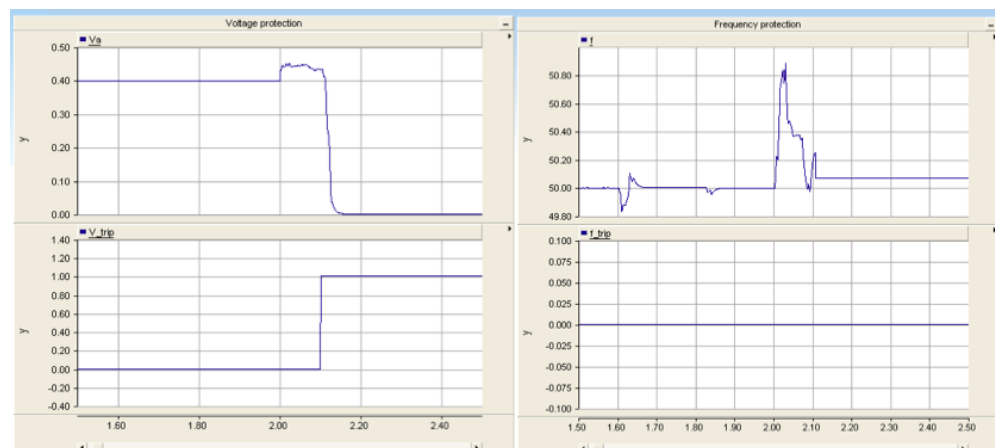
4.5 Islanding protection

Islanding protection is very important because if it doesn't work it could cause serious damage to the system. Islanding situation is simply when the normal grid disconnects locally and the wind farm continues to supply the local grid. Most of the time wind farms are not powerful enough to supply the whole grid distort local grid frequency. For islanding use try to avoid in any situations. Islanding protection needs control of the voltage and frequency.

Tampere University of Technology simulated islanding protection to the grid. Setup values was for overvoltage (106% 0.1sec) down voltage (90% 0.1sec) and over frequency (50.4Hz 0.1 sec) down frequency (49.6Hz 0.1 sec). Simulation plants simulated short-circuit generator because it simulated the rectifier better than the synchronous machine. There wasn't an option to use a rectifier in simulation program. There were three power balances, three fault situations and simulation to inverters. The purpose was to find out could the plant disconnect correctly.

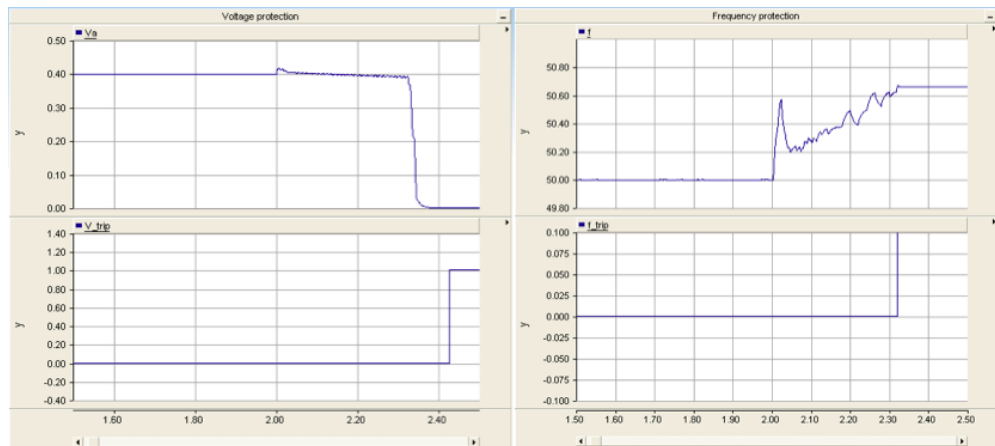
4.5.1 Power load situations

Islanding situation one is a production of 6MW and -0.5MVar and consumption at Käsän output 1.12MW and 0.23MVar. In this situation isle is easy to detect. Voltage protection operate quicker than frequency protection. The frequency spike at the beginning couldn't launch relay but frequency will rise soon out of the limit. Time to disconnection is 0.1 sec.



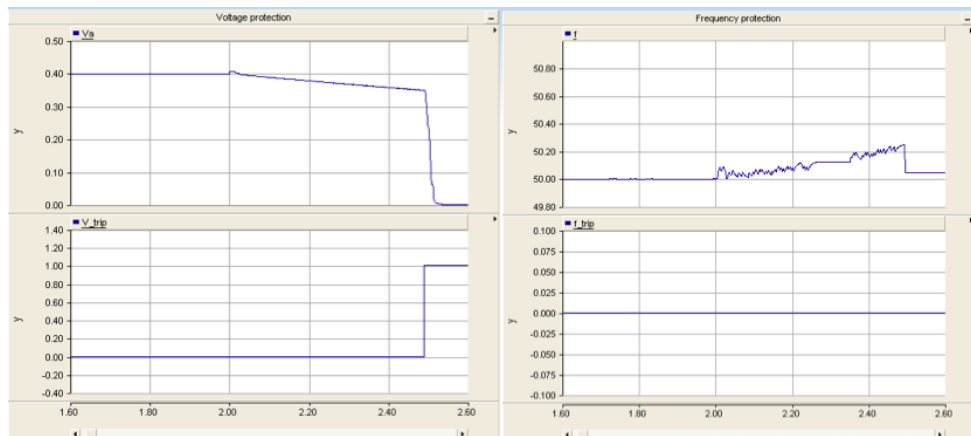
Picture 5: Simulation result of first simulation.

The second situation is one plant at grid production 2MW. Isle protection doesn't wake-up when isle happens because voltage spikes are not enough high and after that it starts to decrease. Frequency protection operates quicker when frequency increases. Time to disconnection is 0.35 sec.



Picture 6: Simulation result of second situation.

The third situation is when production and consumption is almost the same (1.1 MW). Frequency doesn't rise significantly because of balance of active power. Voltages decrease slowly to launch voltage protection. Disconnection time is 0.5 sec.

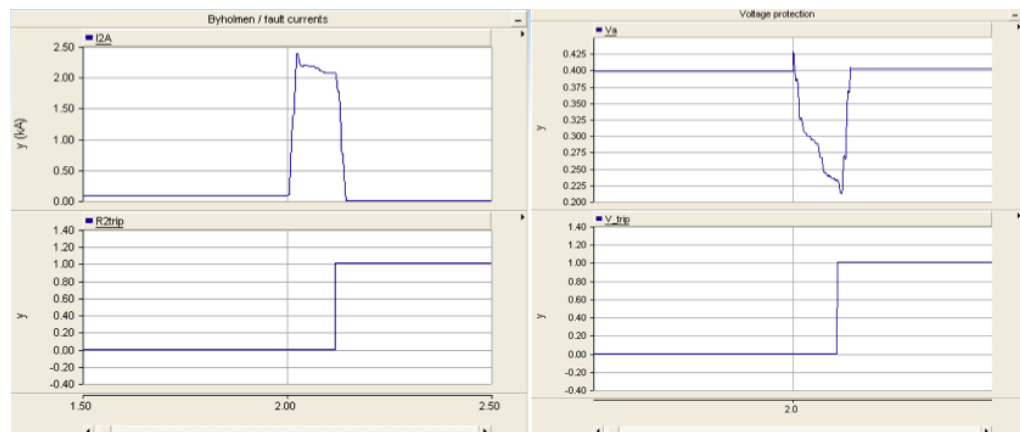


Picture 7: Simulation result of third situation

The significance of voltage protection is dependent at the balance of reactive power at the islanding. If plants are adjusted to product reactive power to the grid then islanding could remain even 4 seconds. For this reason power factor adjustment should be only in inductive direction. In the last situation the plant could maintain voltage to the whole output reasonably well. This could cause failure for reconnections.

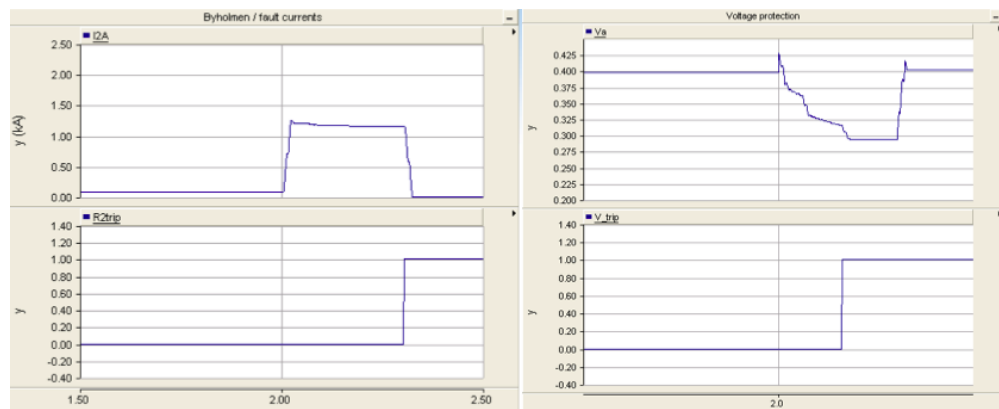
4.5.2 Fault condition simulations

The first situation is when a three-phase fault is adjacent to the Byholmen output at the beginning. The plant will disconnect from the grid because the voltage dip is too great to protect the system. Protection relay operates in 0.1 second and disconnects plants unnecessarily from the grid.



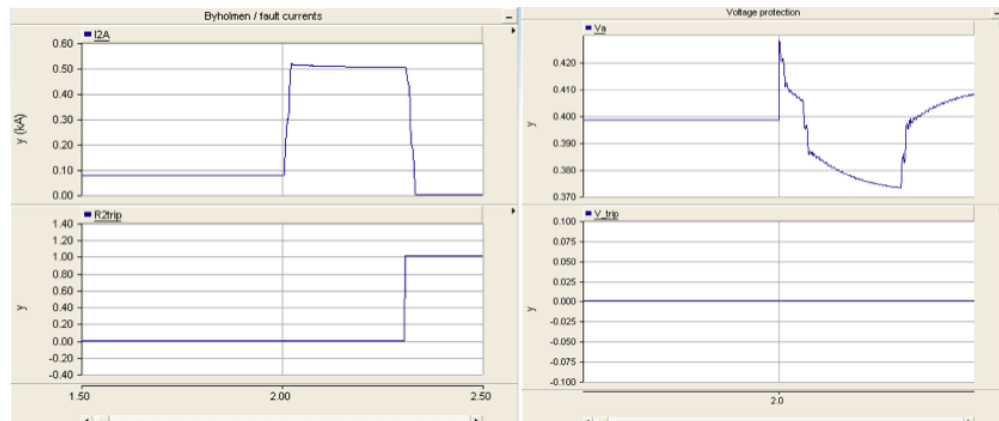
Picture 8: Simulation result of first fault situation

The second situation is when the short circuit is farther from Byholmen output. Voltage sag is smaller this time but it is a great enough to disconnect plants unnecessarily from the grid. Protection relay operates in 0.3 seconds.



Picture 9: Simulation result of second fault situation.

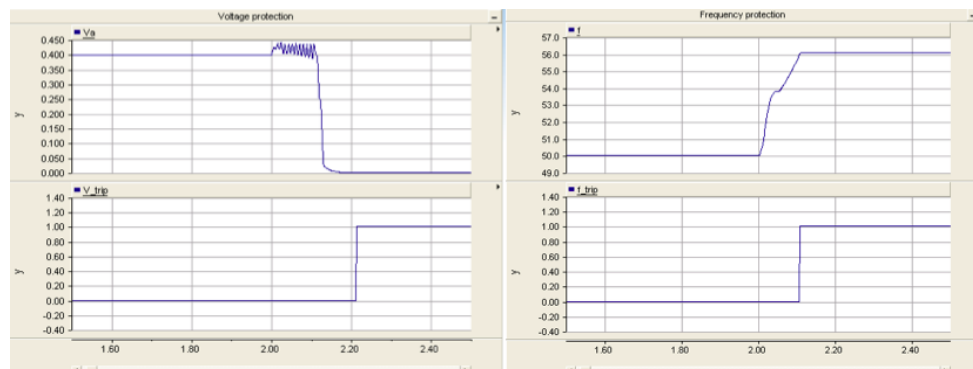
The third situation is when the short circuit is farther than the first two short circuits. There is a voltage sag but it doesn't disconnect plants from the grid.



Picture 10: Simulation result of third fault situation.

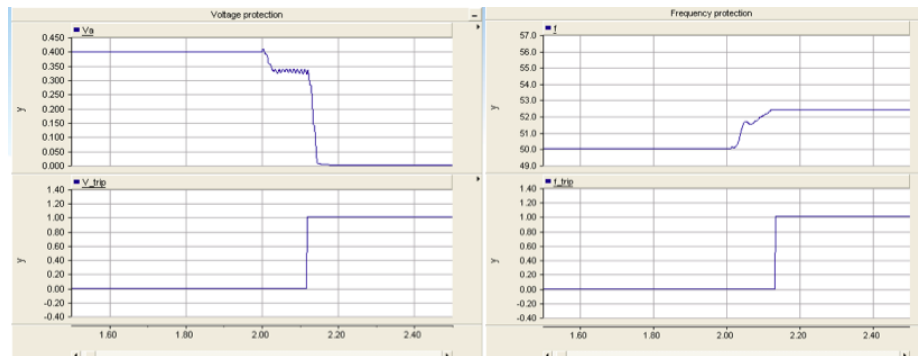
4.5.3 Inverter simulation model

In the first situation production is 1.6MW and power factor 1. At test frequency relay operate first in 0.1 seconds because the frequency rises very fast.



Picture 11: First inverter simulation result

in the second situation production is 0.8MW and power factor 1. Isle disconnect at 0.1 second. It is used for inverter based model on the application of fuel cells, wind power when the moment of inertia should not be looked after. The adjuster can work in many different ways according to use. Byholm-output faults, the situation is the same as the model Adjuster short-circuit generator sides; power plants become detached from the network of such defects unnecessarily.



Picture 12: Second inverter simulation result

4.5.4 Conclusions of isle protection

For suggested protection setup could avoid islanding situations enough reliably. Theoretically possibility for the perfect power unbalanced situation could be plausible but option for that has to be assessed separately. If plants operate for power factor 1 or consuming the reactive power could protection operate more reliably. Islanding situation could be 0.5 second and it could cause problem with speed reclosing. Short circuit generator modelling could also effect islanding model unfavorable way.

Faults in the Byholmen output could disconnect plants unnecessarily from grid this could cause too sensitive voltage protection. Faults which are separated with the speed reclosing could also cause unnecessary disconnection to the plants. When faults are far in the output they don't cause enough great voltage sag which could separate plants from the grid. It should research what a kind setups could help avoid unnecessary disconnections. When right setups are found in islanding protection is possible assess whether frequency variation relay necessary.

Recommended new setups

Over voltage quickly: higher 110% launch time 0.05s

Over voltage slow: higher 106% launch time 60s

Under voltage quickly: smaller than 70% launch time 0.05s

Under voltage slow: smaller than 90% launch time 10s

Frequency over 51Hz launch time 0.2s

Frequency under 47Hz launch time 0.2s

These setups could help with problems of faults in next outputs and could make possible that quickly reconnecting are reliable to use.

4.6 Voltage sags

Grid faults are voltage sags to plants and this could cause plants to accidentally disconnect. When Käsna's output is at maximum load condition 6MW disconnection causes 3.2-4% voltage change. The recommendation is that a 3% change should not happen more often than every hour. Therefore, the plant should be connected to the network as long as possible, because the wells voltage tolerance is an economic power-generators. Including the power plant dimensioning can affect how the plant recognises the burden on the electricity grid failures.

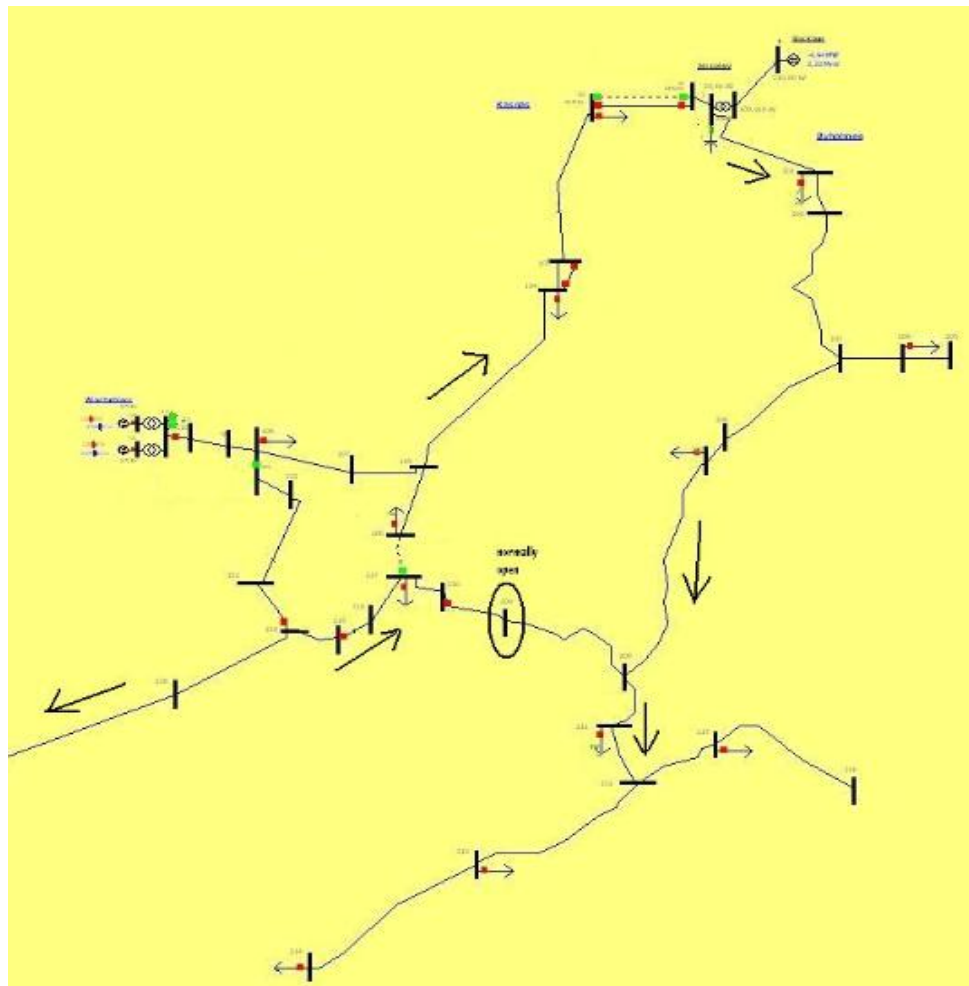
5. Independent part of the planning

Last main part is independent designing. It base fully on the local distribution system details from Fortum. The aim was to design the distribution system whole again for my own. It wasn't simple because I couldn't get all detail for how much distribution system could load.

I was design two wind plants in same place where there are in real, they full production is 2MW each so whole wind farm production is 4MW. Wind plants are connected to Käsna's output. Electric consumption in area are between 0.8MW to 2.7MW power quality in area are very good because power factor is everywhere 0.96 or very near. Most of consumption is near of the 20/110kV substation.

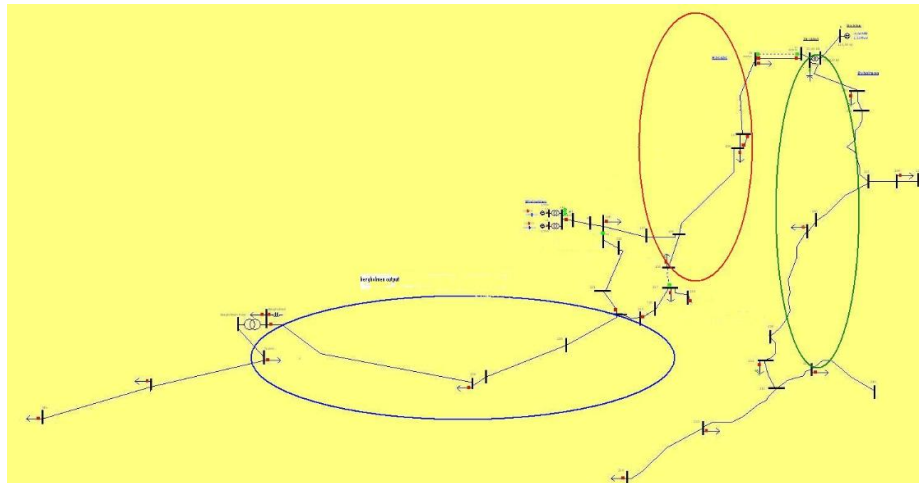
5.1 Structure of distribution system

Because of a area which is typical Finnish rural area, which is very thinly populated. There is also few things which make this area special: Those are Sea and islands. In the area come only one 110kV line. This make problem if it not reliable because there are not possibility to supply area from different direction. Inside of are is possible to make a Byholmen output and a Käsnäs output to ring loop. There is restriction that wind farm could not allow supply Byholmen output from reach final to connection point because output are not rated for so great power. There is also third output, Bergholmen. It is connected after Käsnäs output or Berholmen output. Consumption on Bergholmen is very small less than 0.5MW in every situation. There is also Voltage increase transformer which adjust voltage in right level.

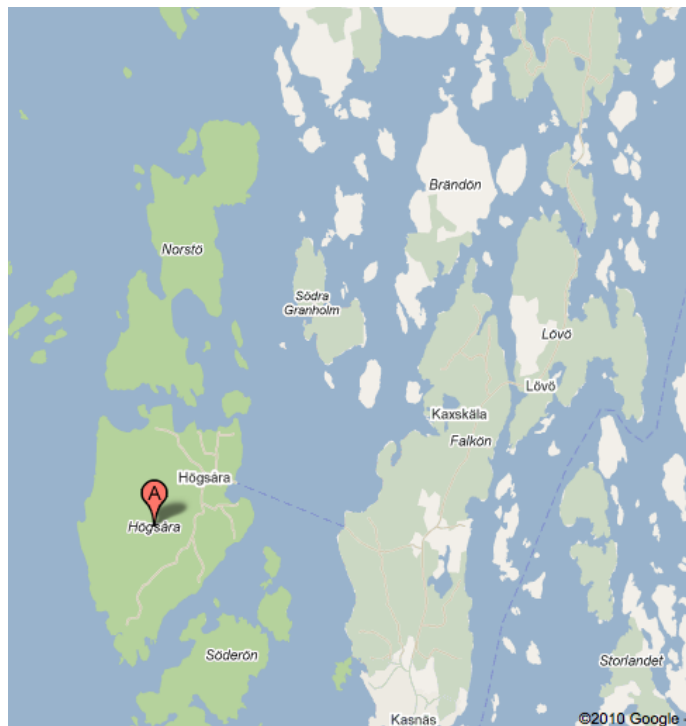


Picture 13: normal current direction with full 4MW production: Käsnäs output is left side and Byholmen output right side. Circuled isolator separate normally outputs.

I planned that a Bergholmen output is part of a Käsnäs output because windfarms give possibility to control reactive power and voltage level in the Bergholmen. If Bergholmen is part of a Byholmen output this advantage is lost but in this situation Käsnäs and Bergholmen outputs are equal with consumption, this could help little bit in fault condition voltage sags.



Picture 14: three outputs red is the Käsnäs output, Green is Byholmen output and blue is Bergholmen output.



Picture 15: Map of area where Distribution area locate

5.2 Current flows

Because of grid nature current could flow very different directions and loads could be varying very much. Most of times highest demand of electricity is wintertime, because of Finnish cold winter. Electricity consumption could very much lower on summer time.

The Käsnäs output has to sizing most greatest current, because of the wind farm and there is also most of local consumption. When wind farm has full production could power flow from the wind farm to

10/220kV substation 1.29 to 3.55MW. To the Bergholmen output flows less than 500kW which make it smallest area with electric consumption. The Byholmen output will need 900kW in normal load situation. If there are fault in Käsnäs output has to all power flow to this area via the Byholmen output which increasing power in this output 0.85MW to 2.6MW in this situation wind farm are not in operation.

Because of wind condition it is most likely that wind farm will product most of year around 2MW. This reason wind farm could supply the Käsnäs and Bergholmen output, but to supplying to Byholmen grid need 500kW from 110kv grid. This is only in high demand situation. In low demand situation wind farm could supply easily whole area power demand and supply over 1MW to the grid. Minimum power need in this area is 0.85MW.

5.3 Fault condition

In the designing of distribution system is very important to designing also cope to fault condition, always it is very easy to design distribution grid to discrimination well. Most of times when adding wind farm in the grid which is decentralized production could make grid designing more difficult because structure of grid are not so simple. One big thing is Islanding protection this disconnect wind farm from grid if it is without Voltage because most of times wind farm could not keep the voltage and frequency level enough good.

There is two fault places which could cause very much re-organizing to grid. They also change easily current directions in some places.

5.3.1 Fault situation 1

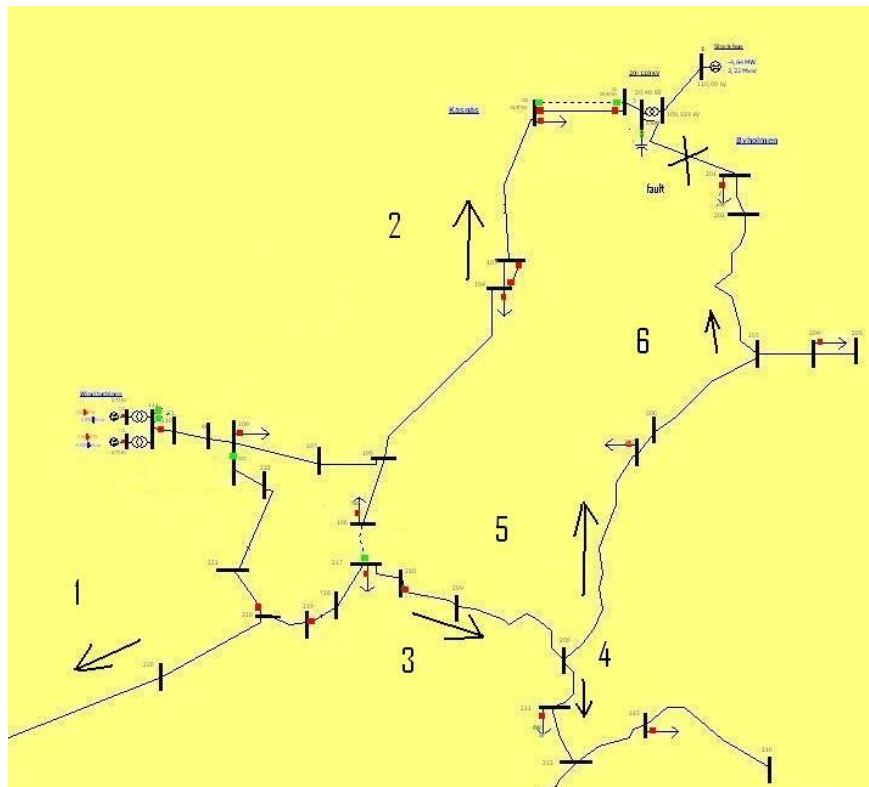
The first situation is when fault place is very beginning of the Byholmen output

Power1 to Bergholmen keep same and no direction change.

Power 2 to wind farm to 20/110kV substation current is smaller than usual because the Byholmen output power don't go this way. Estimated power is 0.9MW smaller than normal situation.

Power 3 are normally very small but this is route which connect the Byholmen output to Käsns output, in this direction power is 0.9MW or less. This is also important spot when fault spot connecting back to grid, because normal situation power supply should go any father than transfer border is normally.

Power 4 has not any changes because it not a loop.



Picture 16: shows power 1-6 direction

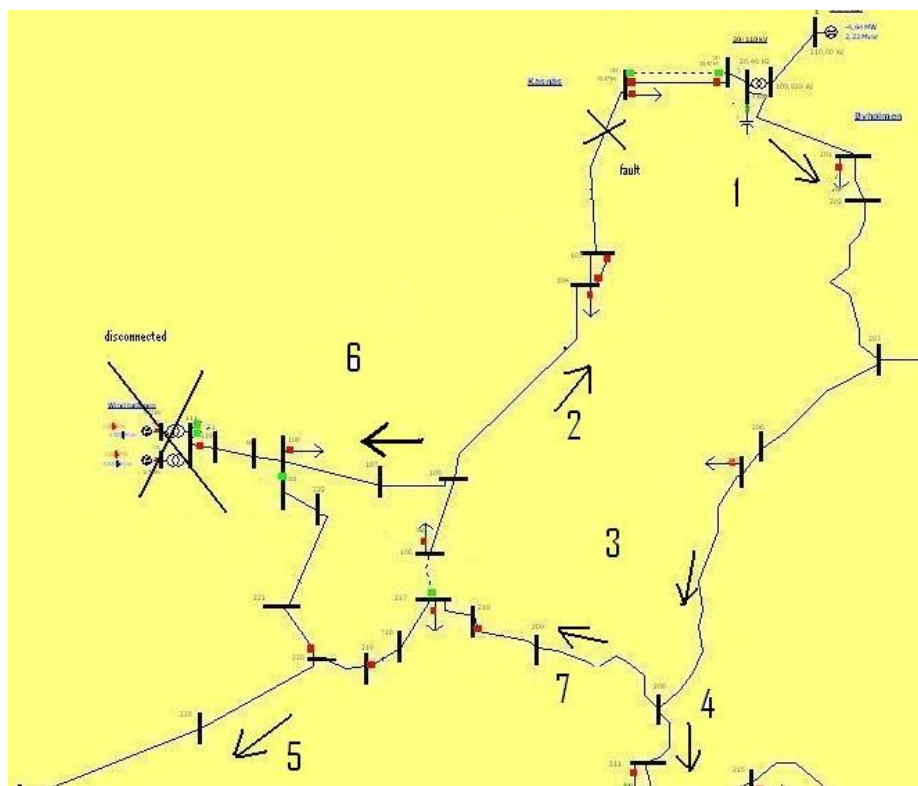
Power 5 flows different direction than normal and it is 0.19MW and it is smaller also. If fault is this part of grid it could be isolated without bigger problems to customers.

Power 6 flows also different direction and normally in this part power is around 1MW and now it is 70kW

These power flow changes could give reason to use in some point directional relays because powers are not same in different directions.

5.3.1 fault situation 2

The second fault situation is when fault is beginning of the Käsniäs output. This kind situation is quite bad because wind farm has to disconnect also and it's not allowed connect to grid before the Käsniäs output is connected back to 20/110kv substation.



Picture 17: power flowing in fault situation 2

Power 1 flows at normal direction but it is higher than usual because normally it is 0.9MW and now it could be even 2.6MW so this part of grid has to definitely sizing for the this situation.

Power 2 flows normal direction if wind farm is operational. In this part of grid power is much smaller when normally because now it is only 0.33 to 1.16MW and normal situation it could be even 3.5MW

Power 3, 4 and 5 directions are same than usual situation but only Power 3 is much bigger than normal

Power 6 is Flowing to wind farm direction which is opposite of normal, but it is much smaller. Local consumption in that place are only 41kW.

In both exceptional situations voltage could be reduce little bit lower than usual when distance are much longer but these kind arrangements still improve reliability of distribution.

5.4 Voltage sags during the fault situation

The fault situation cause normally voltage sag during the fault time. Voltage sags dependent of impedance of fault place. Impedance are also dependent of distance to generator and power which is in the grid.

$$\underline{U}_{\text{sag}} = \frac{\underline{Z}_L + \underline{Z}_F}{\underline{Z}_S + \underline{Z}_T + \underline{Z}_L + \underline{Z}_F} \cdot \underline{U}$$

Z_L =Line impedance

Z_F = Fault place impedance

Z_S = Generator Impedance

Z_T = Transformer Impedance

U = Line Voltage

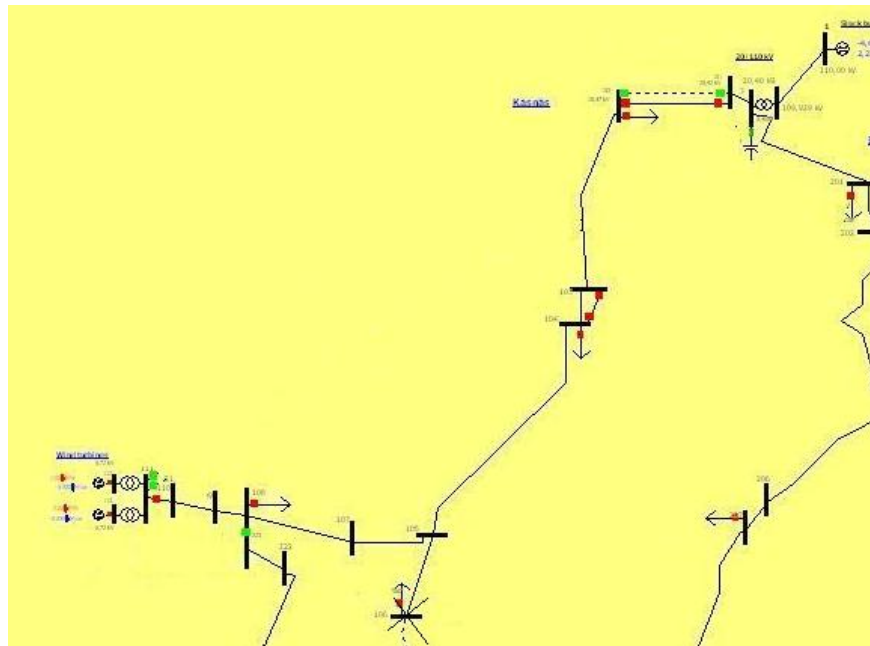
U_{sag} = Voltage sag

In calculation are used PU-system to determine Z_S , Z_T . Z_F are used in ground contact situation 0Ω . Z_S is all calculation 5% and Z_T is 6%. Z_L are calculated from Fortum excel sheet where they are calculated grids R and X. Impedance are always calculated from 20/110kV substation to fault place. U are used in every situation used Nominal voltage which is 20kV. Power which I used in calculation is normal situation power when wind farm is full production.

$$Z_{base} = \frac{V_{base}^2}{S_{base}}$$

5.4.1 Fault in place 1

Place is in the Käsñäs output near of wind farms and are has high power when wind farm is a operational.



Picture 18: fault place 1 marked with x

Calculating Z_{base} value

$$Z_{base} = \frac{20kV^2}{3.5MW} = 114 \text{ Ohm}$$

Transformers impedance

$$Z_T = 114 * 6 = 6.857 \text{ Ohm}$$

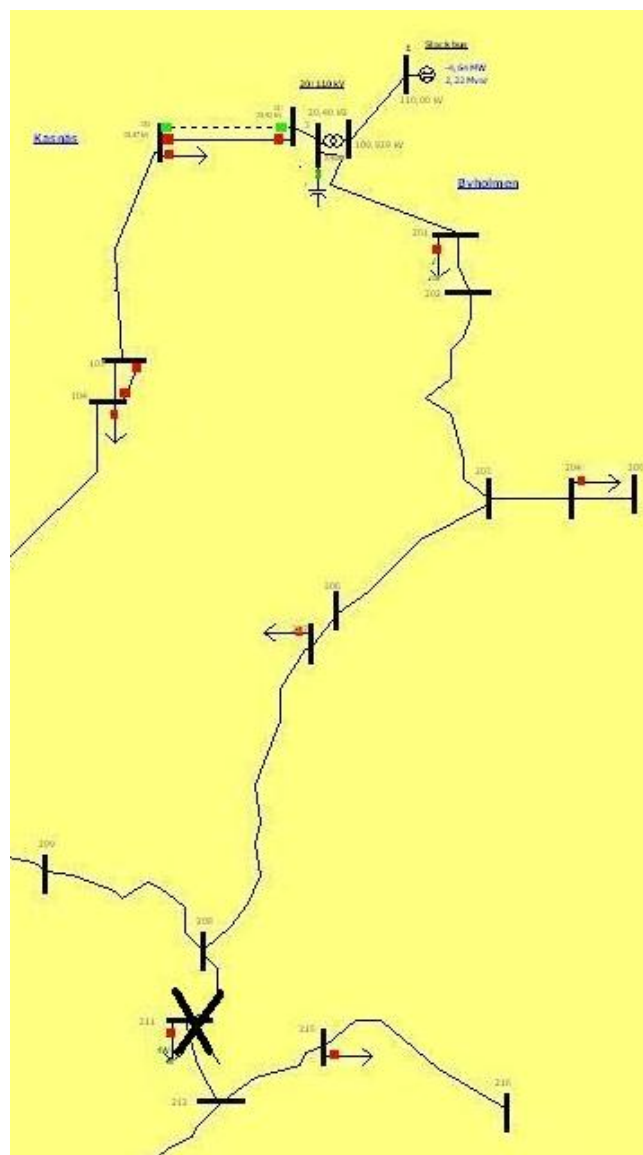
Generator impedance value:

$$Z_s = 114 * 5 = 5.714 \text{ Ohm}$$

Line overall impedance in that point is 1.17Ω . in ground contact fault voltage sag is 1700 V and it is 8.5% of nominal Voltage. If power is smaller will be voltage sag also much smaller.

5.4.2 Fault situation in place 2

Fault place 2 is a Byholmen output where power level is much smaller, but it's also farther from substation and Z_L is 3.21Ω



Picture 19: Fault place 2

Z_{base} to fault 2

$$Z_{base} = \frac{20kV^2}{0.85MW} = 470 \text{ Ohm}$$

Transformer impedance

$$Z_T = 470 * 6 = 28.24 \text{ Ohm}$$

Generator impedance

$$Z_S = 470 * 5 = 23.53 \text{ Ohm}$$

Voltage sag in ground contact situation is 1167 V which is 5.8% of nominal voltage. The voltage sag are smaller in the Byholmen output than the Käsna's output.

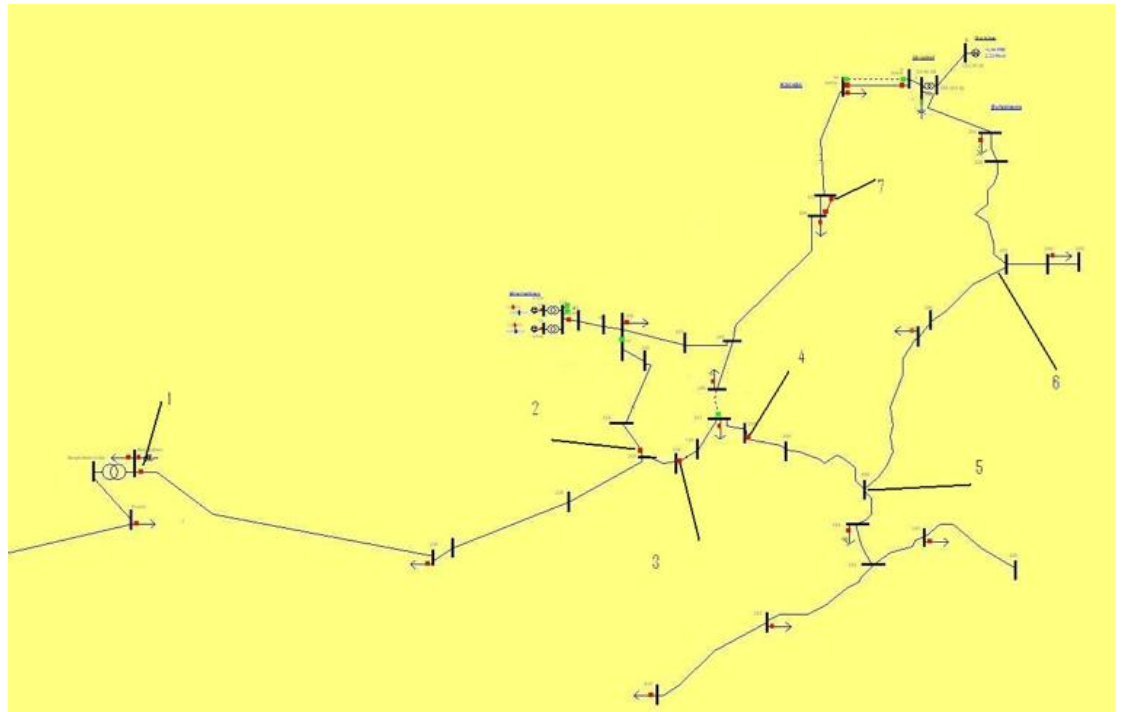
5.5 Protection of grid

Distribution system has to be protected with relays. Normally lines are protected with short circuit, earth connect and over current. These functions are most of a time in same relay.

In this grid need many of these relays and some of them are useful then they are directional, because some part of grid currents are different when they go alternative direction.

Relays need also time setup which help to grid discrimination which is very important of reliability of electric distribution. Without time setup could wrong relay operate and disconnecting bigger area which is necessary. Objective is, when fault come in the grid nearest relay operate first and it is furthest from substation or part which supply electricity to the grid.

When I planned protection system to the grid I shared every relays to different steps. Step1 operate quickest if fault is on relays operation zone.



Picture 20: Relays positions

Position 1 need to be step 2 relay, because there are only 400/20kV transformers and voltage increasing transformer. Relay is directional because there is only one way supply.

Position 2 is step 3 relay because it need little delay for next relay. Relay is directional because via this point goes power to Bergholem and some fault situation also to Byholmen.

Position 3 is step 4 relay and non directional because in this spot power could flow in both ways and this relay is back up relay for number 2 if grid is organized different way from wind farm. Normally this relay protect one output

Position 4 is also step 4 relay and it's directional to Byholmen and it's operational when the Byholmen output are connected to the Käsnäs output.

Position 5 is step 2 relay which protect grid which is south on it and it is directional because that part of grid are not in the loop.

Position 6 could be two directional relays. Relay which is directional North to south is step4 relay and it protect grid when the Byholmen output is connected to 20/110 kV substation and power flows there to grid. Second relay is step 3 relay which protect grid when power flow is inverse. This is important because powers are very different in both ways.

Position 7 relay is step 5 and it's also nearest relay before 20/110kV substation there relay should be step 6 to the Käsniäs output and Step 5 to the Byholmen output.

Relays in wind farm should be step 4. All relays time should be quickly as possible because too long faults could trip off wind farm protection and isolate wind farm unnecessarily from grid.

Directional relays improve most of place over current protection because many of places currents are very different depending of direction of current. However using to grid in ring is here unlikely and only after fault. In Finland condition it's most recommended use only earth contact protection in directional.

6. Conclusions

Product wind energy is good method make renewable energy and in Finland condition it is a only renewable energy which production is possible increase with bio mass burning. Today is almost impossible increasing hydro energy production because all of capacity is in use, mostly in Lapland. Using of solar energy are not profitable because of long and dark winters. There is also problems in wind energy because on shore wind is not most of times enough strong and where are most of wind are only few people.

Slow speed solution are good development for wind production it give better efficiency and is more silent than solutions with gearbox and there is also one main part less to maintenance. Synchronous generator gives also opportunity to improve power quality and because of wind turbines could avoid to building capacitor bank in the area. It is also very important that wind farm disconnect correctly because unnecessary disconnection cause voltage sag to distribution system. Wind farm also decrease grid power losses which is great thing with produced energy. Wind farm is part of distribution system and it make some problems to production unit because it is more vulnerable if it connected straight to base grid. Wind farm also make distribution system protection more complicated and some companies are little bit shy to investing to wind energy.

My own design and analysis part is little bit different than normally in Finland, specially use of directional relay, in practice distribution system are used radial way. Best benefit is most of times to locate faults. In Finland has lots of forest and sometimes middle voltage faults are very hard to find specially if they are loop in rural area. But method of organize grid could be different in every distribution company.

This project was very useful for me I learned very much for wind energy and distribution system which is very useful information to further. Now I know how distribution system react to stress or fault situation.

Sources

1. http://www.ee.lut.fi/courses/Sa2721200/seminaariraportit_s2006/Kallava_tuulivoimaloiden_generaattori_ja_sahkokayttovaihtoehtojen_vertailu.pdf 20.2.2010

2. Conceptual survey of Generators and Power Electronics for Wind Turbines

L. H. Hansen, L. Helle, F. Blaabjerg, E. Ritchie, S. Munk-Nielsen, H. Bindner, P. Sørensen and B. Bak-Jensen.

<http://www.risoe.dk/rispubl/VEA/veapdf/ris-r-1205.pdf> 23.2.2010 11am)

3. https://noppa.tkk.fi/noppa/kurssi/s-18.../S-18_3153_luentokalvot_8.pdf 5.5.2010

4. Material from Fortum and Tampere University of Technology, some of was presentations and excel file. Also lots of non-written material

Picture 1, 2 are from school material from Heikki Tarkianen

5. <http://www.tuulivoimatieto.fi/> Picture 3 are from also here.

6. <http://www.Fingrid.fi>

7. Wind Energy handbook 2001. Burton Tony, Shape David, Jenkins Nick, Bossanyi Ervin